GEOLOGIC MAP OF THE RUSALKA PLANITIA QUADRANGLE (V-25), VENUS

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The Magellan Mission

The Magellan spacecraft orbited Venus from August 10, 1990, until it plunged into the venusian atmosphere on October 12, 1994. Magellan had the objectives of (1) improving knowledge of the geologic processes, surface properties, and geologic history of Venus by analysis of surface radar characteristics, topography, and morphology and (2) improving knowledge of the geophysics of Venus by analysis of venusian gravity. The Magellan spacecraft carried a 12.6-cm radar system to map the surface of Venus. The transmitter and receiver systems were used to collect three datasets: synthetic aperture radar (SAR) images of the surface, passive microwave thermal emission observations, and measurements of the backscattered power at small angles of incidence, which were processed to yield altimetric data. Radar imaging and altimetric and radiometric mapping of the venusian surface were done in mission cycles 1, 2, and 3, from September 1990 until September 1992. Ninety-eight percent of the surface was mapped with radar resolution of approximately 120 meters. The SAR observations were projected to a 75-m nominal horizontal resolution; these full-resolution data compose the image base used in geologic mapping. The primary polarization mode was horizontal-transmit, horizontal-receive (HH), but additional data for selected areas were collected for the vertical polarization sense. Incidence angles varied from about 20° to 45°. High-resolution Doppler tracking of the spacecraft was done from September 1992 through October 1994 (mission cycles 4, 5, 6). High-resolution gravity observations from about 950 orbits were obtained between September 1992 and May 1993, while Magellan was in an elliptical orbit with a periapsis near 175 kilometers and an apoapsis near 8,000 kilometers. Observations from an additional 1,500 orbits were obtained following orbit-circularization in mid-1993. These data exist as a 75° by 75° harmonic field.

Radar backscatter power is determined by the morphology of the surface at a broad range of scales and by in this region are thin, or at least interfingered with unit sRn. the intrinsic reflectivity, or dielectric constant, of the material. Topography at scales of several meters and larger can produce quasi-specular echoes, with the strength of the return greatest when the local surface is perpendicular locality at lat 1° N., long 161° E.). This unit has mainly low-backscatter values but includes patches of very high to the incident beam. This type of scattering is most important at very small angles of incidence, because natural backscatter, low-reflectivity material consistent with a very rough surface. These abrupt changes in radar characsurfaces generally have few large tilted facets at high angles. The exception is in areas of steep slopes, such as ter are interpreted as representing variations in volcanic facies analogous to pahoehoe and aa flows on Earth, and ridges or rift zones, where favorably tilted terrain can produce very bright signatures in the radar image. For most as such might not imply separate geologic units (compare with Campbell and Campbell, 1992). Wrinkle ridges other areas, diffuse echoes from roughness at scales comparable to the radar wavelength are responsible for varia- and northwest-striking fractures control much of the distribution of unit sfRn flows; unit sfRn flows also highlight tions in the SAR return. In either case, the echo strength is also modulated by the reflectivity of the surface material. The density of the upper few wavelengths of the surface can have a significant effect. Low-density layers, unit stRn flows merge and blend into a featureless region of unit fu to the north of Ran Colles. such as crater ejecta or volcanic ash, can absorb the incident energy and produce a lower observed echo. On Venus, a rapid increase in reflectivity exists at a certain critical elevation, above which high-dielectric minerals or canic shields mapped as Zaryanitsa Dorsa shield field material (unit sZy, type locality at lat 1° N., long 169° E.). coatings are thermodynamically stable. This effect leads to very bright SAR echoes from virtually all areas above

Unit sZy shows high to intermediate backscatter that surrounds and comprises the annulus of Hannahannas and The measurements of passive thermal emission from Venus, though of much lower spatial resolution than the corona structures deform unit sZy (see the "Tectonic Structures" section below). A composite unit comprising SAR data, are more sensitive to changes in the dielectric constant of the surface than to roughness. As such, they low-backscatter pitted shields and flow units, designated as upper Zaryanitsa Dorsa shield field and associated can be used to augment studies of the surface and to discriminate between roughness and reflectivity effects. flow material (unit sfZy, type locality at lat 3° N., long 168° E.), undeformed by corona structures, ponds within Observations of the near-nadir backscatter power, collected using a separate smaller antenna on the spacecraft, the coronae and debouches out through gaps in the annuli. were modeled using the Hagfors expression for echoes from gently undulating surfaces to yield estimates of planetary radius, Fresnel reflectivity, and root-mean-square (rms) slope. The topography data produced by this techniN., long 171° E. (flow material of Iseghey Mons, unit mI), Lamashtu Mons (flow material of Lamashtu Mons, que have horizontal footprint sizes of about 10 km near periapsis and a vertical resolution of approximately 100 unit mLm) at lat 2.5° N., long 173° E., and Muhongo Mons (included in Muhongo Mons and associated small m. The Fresnel reflectivity data provide a comparison to the emissivity maps, and the rms slope parameter is an shield-sourced flow material, unit smM) at lat 11° N., long 174.5° E. The shared criteria include an obtuse conical indicator of the surface tilts, which contribute to the quasi-specular scattering component.

The Rusalka Planitia quadrangle (herein referred to as V-25) occupies an 8.1 million square kilometer swath of lowlands nestled within the eastern highlands of Aphrodite Terra on Venus. The region (25°-0° N., 150°-180° E.) is framed by the crustal plateau Thetis Regio to the southwest, the coronae of the Diana-Dali chasmata complex to the south, and volcanic rise Atla Regio to the west (fig. 1). Regions to the north, and the quadrangle itself, are part of the vast lowlands, which cover four-fifths of the surface of Venus. The often-unspectacular lowlands of Venus are typically lumped together as ridged or regional plains. How ever, detailed mapping reveals the mode of resurfacing in V-25's lowlands: a mix of corona-related flow fields and local edifice clusters within planitia superimposed on a background of less clearly interpretable extended flow fields, large volcanoes, probable corona fragments, and edifice-flow complexes. The history detailed within the Rusalka Planitia quadrangle is that of the extended evolution of long-wavelength topographic basins in the presence of episodes of extensive corona-related volcanism, pervasive low-intensity small-scale eruptions, and an early phase of regional circumferential shortening centered on central Aphrodite Terra. Structural reactivation both obscures and illuminates the tectonic development of the region. The data are consistent with progressive lithospheric thickening, although the critical lack of an independent temporal marker on Venus severely hampers our ability to test this claim and correlate between localities. Two broad circular basins dominate V-25 geology: northern Rusalka Planitia lies in the southern half of the quadrangle (southern Rusalka Planitia has been described in V-37 [Hansen and DeShon, 2002]), whereas the er Llorona Planitia sits along the northwestern corner of V-25 (fig. 1). Similar large topographic basin occur throughout the lowlands of Venus, and gravity data suggest that some basins may represent dynamic topography over mantle downwellings (Herrick and Phillips, 1992; Simons and others, 1997). Both planitiae include coronae and associated lava flows, as well as fields of volcanic shields. Within each basin, the local geologic histories are relatively well constrained; correlations between the planitiae are difficult without making assumptions. The region between the two basins contains large volcanoes, corona fragments, deformation belts, and shield fields embedded within a topographically higher heterogeneous expanse of rolling plains. V-25's most prominent structural grain is a suite of wrinkle ridges that arc around the southwest corner of the quadrangle. A patchy suite of northeast-trending assorted lineaments underlies much of the map area. Although these lineaments originally were narrow fractures (Young, 2001), this structural suite appears to have subsequently opened up along extensional troughs near Corpman crater in the southwest corner of the map area and been reactivated as wrinkle ridges at Ran Colles in the middle of the southern boundary of V-25. Nineteen impact craters dot the quadrangle. Craters Yazruk, du Chatelet, and Caccini contribute large geology-obscuring ejecta halos. Crater densities are too low for either relative or absolute age dating. Ten splotches, presumably associated with meteor airbursts (McKinnon and others, 1997), also occur across V-25.

The Magellan mission provided east-looking S-band synthetic aperture radar (SAR) coverage over 96% of V-25, supplemented by ~75% east-looking stereo coverage and 5% west-looking coverage. The USGS digital FMAP dataset (at 75 m/pixel) and derived products comprise the map base. Ancillary data used for mapping include the Global Topographic Data Record 3 (GTDR 3) with an effective horizontal resolution of 10 kilometers and similar products containing Fresnel reflectivity at wavelengths of 12.8 cm, average meter-scale slope, and derived 12.8 cm emissivity data (GRDR, GSDR, and GEDR, respectively). GTDR data were combined with SAR images to produce synthetic stereo anaglyphs (Kirk and others, 1992), which played a critical role in elucidating the relationship between geology and topography in this quadrangle. The three orbits of the Magellan high-resolution altimetry experiment (Ford and Pettengill, 1994) also pass lat 7° N., long 158° E. A tight cluster of small shields lies at the summit of Fand Mons, with variegated mediumthrough this quadrangle. In 1985 the Vega 1 spacecraft landed near lat 8.1° N., long 175.9° E. (± 150 km).

backscatter patches (rather than coherent flows) extending down the flanks. The contact with unit fu locally Although the XRF experiment failed, a gamma ray spectrometer obtained potassium, uranium, and thorium abundances (Weitz and Basilevsky, 1993). The methodology for the definition of geologic units and structural fabrics builds on standard geologic analysis, as detailed in Hansen (2000). Mapped units represent material emplaced within an increment of geologic history, to which standard stratigraphic methods have some limited application; however, some units may be composite, in that they might not be stratigraphically coherent over their entire represented area. An example of such a troublesome unit is the flow material, undifferentiated (unit fu) that dominates much of the quadrangle.

IMAGE INTERPRETATION

The interpretation of features in Magellan SAR images is key to developing a geologic history for V-25. The subject of radar image interpretation is explored in depth in Ford and others (1993); topics pertinent to V-25 Kilometer-scale slopes are resolved in radar images as systematic variations in radar backscatter; radar-facing slopes scatter back more radiation than those sloping away from the radar. Converting the range data that AR provides into a plan-view projection also introduces geometric distortions that allow an understanding of the topography. As SAR is very sensitive to slight variations in slope along the direction that the spacecraft is looking, topography is highlighted (although quantifying the topography is in practice very difficult). The S-band (12.8 cm wavelength) SAR also responds to surface roughness at the scale of the radar wavenorthwest-trending axis from the central edifice. These lineaments are best explained as the surficial manifestalength. Rougher surfaces will scatter more radiation back to the oblique-looking radar than a smooth surface. tion of a shallow dike swarm. However, such variations are simply textural, and a direct correlation with stratigraphic units cannot be assumed. 'ariations from pahoehoe to aa within individual terrestrial lava flows present an analogous problem. A key assumption in the interpretation of the rock record on Venus is that liquid water has not played a role in shaping its surface. The primary evidence backing up this view is the extremely dehydrated state of the lower N., long 166.5° E.), respectively. These assorted kipukas cannot be stratigraphically linked together, other than atmosphere (Donahue and others, 1997) and lithosphere (Mackwell and others, 1998), as well as the high surface that unit fu (itself probably polygenetic) is locally superposed upon the composite unit bCl. Unit bCl in some platemperature of ~460 °C (Crisp and Titov, 1997). The assumption eliminates most sedimentary rocks, as there is ces bears a texture of fine-scale lineaments superposed on longer scale undulations very similar to that described no means of deposition, and any exposures of metamorphic rock, as there is no means to expose extensive tracts for the basal material of Urutonga Colles (unit bU). One kipuka of unit bCl is deformed by the small ovoid Clonia of deep crustal rocks. The exceptions relate to impact features; rim materials have presumably undergone shock

Corona, which may indicate that the origin of some of these kipukas could be corona-related. Some small patches metamorphism and fine ejecta have been redistributed by wind. However, volcanic rocks probably make up the majority of the planet's surface. Criteria for distinguishing discrete geologic (as opposed to radar) units include the presence of sharp, contin
Assorted high-backscatter shield patches, ranging from 20 to several hundred kilometers in diameter and uous contacts; truncation of or interaction with underlying structures and topography; and primary structures (for mapped as shield field material around du Chatelet crater (unit sCt, type locality at lat 19° N., long 167.5° E.), lie example, flow channels or edifice topography) that allow a reasonable geologic interpretation, and thus hints at a near du Chatelet crater. Some portions of unit sCt are partially obscured by the thick ejecta halos around du Chathree-dimensional geometry. Some mapped units fail to fit these constraints, limiting their use in constructing telet and Caccini. Summit pits are rare, as is noticeable topography; the main criteria identifying these as shields stratigraphic schemes; unit fu is an example. A range of structures, both primary (depositional) and secondary (tectonic) are identified in the Magellan SAR data. Primary structures include canali (sinuous, low-backscatter topographic troughs hundreds of kilome-both north-trending kilometer-scale tensile-fracture ribbons (after Hansen and Willis, 1998) and east-west-trendters long and a few kilometers wide, as described by Baker and others [1992]), rilles (hundreds of meters wide, ing ten-kilometer-scale ridges, with intervening troughs flooded by unit fu. The hypothesis of Hansen and Willis often complex, incised channel forms) and channels (sinuous low-backscatter features). As water is not thought to exist on Venus, the most likely fluid to form these features is low-viscosity lava A class of primary structures commonly forming patchy small-scale radar units (called shields after Crumpler and others, 1997) likely represents the manifestation of local volcanic flows. For the purpose of this investiwhen local temperatures kept the competent surface layer thin. The longer wavelength ridges are likely latergation, we define three end member modes (although most occurrences are mixtures of all three): Shield edifices—2- to 20-kilometer-diameter circular deposits having visible topographic relief and occasional summit pits Shield blotches—2- to 20-kilometer-diameter circular deposits having no discernible topographic relief but

Shield flows—irregular, often expansive deposits having some summit pits, little topographic relief, and Most radar lineaments likely represent secondary structures. Extremely fine, sharply defined continuous structure marks unit sRk material; instead, penetratively developed sinuous ridges and prominent scarps cut the radar-bright lineaments, typically within the plains, have been interpreted as fractures (Banerdt and Sammis, unit. The topography and outcrop patterns both indicate the presence of dismantled coronae. The unit sRk com-1992). Many commonly widen along strike to form grooves (paired dark and bright lineaments, spaced by no plex appears to be embayed by unit fu. A complex canali system emerges from the unit sRk complex south of more than a couple of kilometers and with the dark lineament closest to the spacecraft). If the fracture is associated with pits (sharply defined depressions commonly less than a kilometer in diameter), the fracture probably represents the surface expression of a dike at depth. Paired dark and light lineaments that are more than a few The inverse in SAR of a groove is a ridge (light and dark lineaments a few kilometers across); on Venus tially expansive) tectonic structural suites. An example is the wrinkle ridge fabric covering most of the quadranridges either have parallel edges with moderate sinuosity at the 10-kilometer scale and have an across-strike gradation in backscatter (a form specifically called ridges in this text) or have a more erratic plan view, with frequent concentric patterns of ridges or grooves) are the most obvious case (see fig. 7). right-angle interruptions at the 10-kilometer scale and variations in across-strike width (wrinkle ridges). Positive

The identification of structural fabrics does not necessarily mean that they represent single, instantaneous linear topographic features hundreds of kilometers across and thousands of kilometers long but too subtle to be time-stratigraphic markers, or even that the structures within a suite have a single genetic cause. For example, the

Whether these textures relate to emplacement or later tectonic deformation is not known. Neither origin nor

Unit sU comprises multiple 10-kilometer-diameter subdued circular edifices interpreted as volcanic shields

cut unit bU and unit sU but not unit fu. The undifferentiated flow material bears most of the canali in the quadran-

some tectonic structures, but suppress others. Some Venus mappers (for example, McGill, 2000; Johnson and oth-

ers, 1999) have called similar units "regional plains." Although this may be a correct geomorphic description, we

prefer a name that provides our interpretation of the likely mechanism of emplacement of the geologic unit (as

unit fcIt lava. Dark ejecta halos surrounding Yazruk and du Chatelet craters obscure the eastern end of Tie Fluctus.

Stratigraphically intertwined with unit fcIt is a complex of ~5-kilometer-diameter shields and extended lava

sfL were emplaced as very low viscosity lavas; the individual volcanic centers, although showing central pits, dis-

play no evidence for discernible radial slopes, and where superimposed on canali, unit sfL flows up to 100 kilo-

STRATIGRAPHY OF NORTHERN RUSALKA PLANITIA

High-backscatter volcanic flows mapped as Zaryanitsa Dorsa regional flow material (unit fcZy, type locality

The flow material of Ituana Corona (unit fcIt; type locality at lat 22° N., long 154° E.) is stratigraphically

flows) and that reflects our understanding of the stratigraphy of the unit (in that we do not really understand it).

west-northwest-trending graben suite and the north-northeast-trending ridges that together define Oya Dorsa.

frequent summit pits:

emplaced before a northeast-striking fracture suite.

tively developed north-northeast-trending ridges of Oya Dorsa are unclear.

m resolution of the Magellan SAR data set.

iations in composition

ern margin of the Rusalka basin.

inliers in the Rusalka Planitia region.

Wrinkle ridges locally deflect unit sfIt flow margins.

face of unit fu bears a subtle kilometer-scale reticulate pattern.

STRATIGRAPHY OF EASTERN LLORONA PLANITIA The oldest materials in the Llorona Planitia region (fig. 1) of the quadrangle are on kipukas (islands in voldike swarms, a monogenetic interpretation may be valid, or at least easier to recover from a structural history that canic flows) composed of two sequential units: the basal material of Urutonga Colles (unit bU; type locality at lat involves reactivation. The related assumption that structures with similar appearance and orientation, but on sepa-10.5° N., long 155° E.) and the younger overlying shield field material of Urutonga Colles (unit sU; type locality rate kipukas, represent a single tectonic event also represents only one possible interpretation of the data—albeit, at lat 3° N., long 151° E.). At least in the southern part of the Llorona region both unit bU and unit sU were in some cases, the simplest. Aside from major tectonic structures described below, unit bU has two scales of geomorphic fabric: very smooth, subdued but irregular undulations with a 10-kilometer horizontal scale and a fine linear fabric at the 100-

REGIONAL STRUCTURAL SUITES The earliest regional structural suites, northwest-trending grabens, are restricted to the southwestern part of the quadrangle. The northwest-trending grabens comprise a west-northwest-striking trough/fracture suite that deforms kipukas of unit bU but are buried by unit sU; fracture spacing is about 1 kilometer, whereas troughs tend to be spaced at 5 kilometers. Both features deflect around topography. Locally, this early suite blends into the fine stratigraphy of unit bU is clear, except that unit bU must have been emplaced before formation of a penetrative linear texture described earlier for unit bU. The general impression is of nearly pervasive thin-layer deformation. Superposed on the northwest-trending graben suite, and cutting both unit bU and unit sU, are northeasttrending lineaments. In the unit bU and unit sU kipukas, the lineaments appear as individual fine grooves (interbased on the presence of summit pits (an inference we repeat throughout the quadrangle). These shields postdate preted as fractures) with an aperiodic spacing averaging 10 kilometers. Northeast-trending lineaments also occur the formation of the suite of west-northwest-trending grabens that cut unit bU. Shield relations with the penetraas fine dark streaks in unit fu, often enhanced by splotches, impact ejecta, or serrations on flow margins. These local relationships may indicate that the northeast-striking lineaments are more extensive than mapped. Reactiva-Embaying the kipukas of unit bU and unit sU is a radar dark composite flow field of unknown origin and tion has modified northeast-striking fractures in the Ran Colles area, where the development of linear northeastunconstrained duration (flow material, undifferentiated [unit fu]; type locality at lat 11° N., long 157° E., although trending wrinkle ridges probably reflects the local contractional inversion of underlying filled fractures. Such variable across map area). Temporal relations are indicated by cross-cutting relations; northeast-striking fractures reactivation is analogous to structural patterns described to the south in V-37 (DeShon and others, 2000; Young, 2001). Near Corpman crater late graben formation also appears to have taken advantage of the earlier structural gle; this relationship may be as much a function of the subdued topography of this unit as a genetic connection. Flows emerging from Ran Colles and from the shield complex (unit sRk) in the northeastern corner of the map Wrinkle ridges are low sinuous ridges a few kilometers wide and up to a few hundred kilometers long and area contribute to unit fu, implying a polygenetic origin. The subdued backscatter properties of the unit enhance are present on most terrestrial worlds, especially on large expanses of volcanic plains (Watters, 1988). Wrinkle ridges cover all but the very southwestern corner of the map area and define the most extensive regional structural fabric in V–25. At the thousand-kilometer scale, the wrinkle ridges clearly arc around the southwest corner of the map area, swinging approximately around Thetis Regio. This pattern was noted by Bilotti and Suppe (1999) and interpreted as a response to loading of the lithosphere by Aphrodite Terra (Sandwell and others, 1997). At smaller scales, however, local topography controls wrinkle ridge orientation, with wrinkle ridges paralsuperimposed on unit fu where the two units are in contact, dominating the region with topographically controlled lel to topographic contours. In some areas (for example, near Zaryanitsa Dorsa and Poludnitsa Dorsa), the flows of moderately high backscatter. Four major flow lobes radiate from Ituana (a local topographic high) and regional wrinkle ridge trend blends into the local structural fabric (corona and ridge belt, respectively). appear to flow into local topographic lows. Contacts between unit fcIt and unit fu do not trace topographic con-The interactions between wrinkle ridges and western Rusalka Planitia flow units imply diachronous wrinkle tours; this observation, taken together with the lobate margin shape of unit fcIt, likely indicates that the total ridge evolution. Along the western margin of unit fcZv, wrinkle ridges are sparse and subdued and are confined to extent of unit fcIt was limited by lava supply. However, successive internal sub-members of unit fcIt contour gentle topographic warps, which follow the regional wrinkle ridge trend. The central portion of the Zaryanitsa around Lumo Dorsa and Oya Dorsa, implying that evolving warp topography played a locally controlling role materials are dominated by spatially penetrative, prominent wrinkle ridges that generally wrap around coronae within the context of time-transgressive emplacement history of unit fcIt (fig. 2). A >300-kilometer-long flow within the Ran Colles and Zaryanitsa Dorsa region but also contains structural elements that converge on individfield, Tie Fluctus, appears to have been fed through a 10-kilometer gap in Oya Dorsa, indicating the mobility of ual corona. Other minor ridge elements link between the major ridges; some parallel the north-east-trending linea-A kilometer-scale reticulate pattern is superimposed on much of unit fcIt, an effect that is shared with other others, 2000). The difference in strain accommodation between regions near Zarvanitsa Dorsa and the margins of lobate corona-related flow units in V-25 (see below). Especially near Ituana Corona, local shields are scattered across unit fcIt; their small area precludes their delineation as distinct units within the corona flows. Channelindependently from that in the rest of the planitia. The more isotropic distribution of wrinkle ridge orientations in forms (some geomorphologically similar to the canali in unit fu) radiate from the raised rim of Ituana Corona. Anomalously low emissivity and matching high reflectivity in some unmapped subunits may indicate slight varontraction related to the topographic evolution of the planitia, instead of the regional loading by Aphrodite Terra predicted by Sandwell and others (1997). An alternative hypothesis is that the lithosphere had different material or thermal properties near the Zarvanitsa complex that resulted in a record of local rather than regional forces. flows west of Ituana Corona mapped as the shield field and associated flow material of Ituana Corona (unit sflt; At the small scale, wrinkle ridges wrap around individual shields, which may indicate either a thin mechanitype locality at lat 20° N., long 151° E.). The shields contributing to unit sflt tend to have low backscatter and lie cal layer with respect to surface topography or very low angle fault elements participate in wrinkle ridge formawithin a broader, internally complex low-backscatter flow field also mapped as part of unit sflt. Many of the tion. Some workers infer that coherent wrinkle ridge networks represent evidence of a single contractional event shields have summit pits that align with lineaments concentric to Ituana Corona. The unit sflt flow field extends (for example, Basilevsky and Head, 1996). However, that interpretation does not allow for reactivation, a process to the west of the quadrangle toward the center of Llorona Planitia, compatible with topographic flow control. hard to distinguish with the available data. An existing wrinkle ridge could act as a tectonic flaw even if it was completely buried in lava flows; as such, the initial age of imposition of a wrinkle ridge fabric may predate its South of Llorona Planitia a series of high- to moderate-backscatter regions comprises irregular ~20-kilometer-diameter shield patches and related extended lava flows mapped as the shield field and flow material of Llorwrinkle ridge formation, with no lower stratigraphic constraint. That being said, documented direct interactions ona Planitia (unit sfL; type locality at lat 13° N., long 151° E.). Patches of unit sfL are superposed on unit fu (and the canali Ikhwezi Vallis and Tai-pe Valles) and Praurime Fluctus (the southern lobe of unit fcIt). Flows of unit exist at the margins of Argimpasa Fluctus (unit fcZy) and on Ran Colles (fig. 3).

deform the entire unit. Argimpasa Fluctus, at large scales, appears to represent a large flow lobe of unit fcZy.

so that parts of the flow may actually be a kipuka. Parts of the Argimpasa Fluctus contact indicate depositional

to volcanic activity (fig. 3A). The Vega 2 landed to the south of V-25 on material likely equivalent to western

unit fcZy. X-ray fluorescence spectroscopy and gamma ray spectrometer data again are compatible with a tho-

ing from southern Rusalka Planitia's Eigin and Saunau Coronae (Hansen and DeShon, 2002). Unit cES is equiva-

lent to unit prR2 (the younger of the then-named "Rusalka regional plains units") described in DeShon and others

gle sf unit of Hansen and DeShon (2002). The lower of the two units, lower Ran Colles shield material (unit sRn,

type locality at lat 0° N., long 163° E.), comprises >10-kilometer-diameter, medium-backscatter shields that

and unit fcZy is gradational, with backscatter homogeneity and the truncation of a kilometer-scale reticulate ridge

pattern developed on unit fcZy. The presence of isolated shields within unit fcZy may indicate that unit fcZy flows

Extended flows dominate the upper Ran Colles shield field and associated flow material (unit sfRn, type

Toward the central Zaryanitsa corona complex, basin-filling unit fcZy flows blend into a field of pitted vol-

Bil Coronae. In places, pit chains and scalloped volcanic domes mark unit sZy. A mesh of wrinkle ridges and

Rusalka Planitia contains three large mountains, each about 200 kilometers across: Iseghey Mons at lat 9.0

topographic profile associated with a local geologic unit; the shared interpretation is that they represent large vol-

canic shield constructs. Due to a large volcano's potentially diachronous history, assigning a stratigraphic position

to these mountains is difficult (for example, Campbell, 1999; Guest and Stofan, 1999) regardless of local contact

SAR, unit smM materials display a high-backscatter assemblage of shield patches approximately 150 kilometers

across with no clear radial trend in the flows (similar isolated shield patches nearby are also lumped into unit

smM). However, synthetic stereo imagery reveals that the bulk of unit smM is on a concentric shield (Muhongo

Mons) rising 1.4 kilometers above the plains. A possible interpretation is that the large volcano simply represents

Iseghey Mons, composed of flow material of Iseghey Mons (unit mI), is ill-defined in SAR. Vague flows

Lamashtu Mons, composed of flow material of Lamashtu Mons (unit mLm), is in between the main portion of

radiate from a kilometer-high topographic shield. There are hints of a wide, scalloped summit caldera. Unit fcZy

(described above) surrounds unit mI, however the nature of the intervening contact is unclear, and the units are

unit fcZy and the Argimpasa Fluctus lobe (also unit fcZy). A low-backscatter lobe of unit mLm extends to the south-

east from the kilometer-high Lamashtu Mons edifice into Argimpasa Fluctus. The shield itself has very low back-

scatter values at the summit that grade into higher backscatter values and then to moderate-backscatter levels at

lower elevations. Some radar-dark distinct flows extend down the high-backscatter flanks of the shield. A train of

small (<1 kilometer), high-backscatter outcrops extends east-west across the summit. Unit mLm blends into unit fR

to the north. Otherwise, pervasive wrinkle ridges are attenuated (though not truncated) around the main construct

STRATIGRAPHY OF THE MARGINAL PLAINS

southwest corner (the Corpman crater area) to the northeast corner (the Romanskaya crater area) of the map, sep-

arating the planitia basins. Because the dominant unit in this region is the potentially incoherent undifferentiated

the traditional descriptive sequence of stratigraphic succession will be abandoned, and units will be described in a

Flows near Corpman crater (unit fCm, type locality at lat 1.5° N., long 152° E.) radiate from a poorly devel-

oped north-trending trough system north of Corpman crater. Unit fCm has variable backscatter patterns similar to

unit mLm, yet it lacks a clear topographic rise. Interactive stretching of the SAR data hints at a significant number

of sinuous rilles within the flows. The contact between unit fCm and unit fu is gradational; a >250-kilometer-long

canali cuts both units. Although a sharp contact can be drawn between unit fCm and an abutting kipuka of unit sU

servative equivalent of unit cSe material described in V-37 (Hansen and DeShon, 2002). Unit fcSe extends radi-

ally from the north-northeast-trending Seia Corona complex (the heart of which is ~300 kilometers south of

Corpman crater). Variegated low-backscatter material lies at the center of the unit; more homogeneous high-back

scatter materials lie at the distal edges. Structural relationships documented to the south (Hansen and DeShon,

2002) indicate that unit fcSe is a composite unit diachronous with respect to the tectonic evolution of the Seia

Corona complex; that interpretation is applied here. In some places, the contact between unit fcSe and unit fu is

sharply truncated, which suggests that unit fcSe was emplaced after the regional northeast-striking fracture suite

appears to follow northeast-trending lineaments, suggesting that unit mF in part postdates unit fu. The contact of

material (unit sfA; type locality at lat 12° N., long 163° E.) comprises medium-backscatter shields and low-back-

scatter shield-sourced flows; unit sfA resembles the geographically distinct Ran Colles complex, which comprises

unit sfRn and unit sRn, to the south. On the northern side of unit sfA, the unit is partially confined to the central

basin of the ill-defined Jarina Corona. On its southern edge, unit sfA blends into unit fu in similar fashion to unit

at lat 14° N., long 162° E. Lahar Mons is made up of homogeneous medium-low-backscatter flows mapped as

in a depression that is 330 kilometers across and 600 meters deep. The sharp circular contact indicates that unit

Lahar Mons sourced flow material (unit mLh) and is topped with a small cluster of domes. The main edifice sits

is their circular planform. A strong kilometer-scale reticulate pattern appears on parts of unit sCt.

formed folds, developing as the surface layer cooled and thickened (Banks and Hansen, 2000).

TECTONIC STRUCTURES

Along the northwest limit of unit sfA is Lahar Mons, a 1300-meter-high, 150-kilometer-wide shield volcano

Asherat Colles, an extensive shield complex mapped as Asherat Colles shield field and associated flow

Fand Mons sourced flow material (unit mF), forms a 130-kilometer-wide, 900-meter-high shield volcano at

The flow material of Seia Corona (unit fcSe, type locality at lat 0.5° N., long 155° E.) is a slightly more con-

flow material (unit fu), a single reliable stratigraphic succession is difficult to determine. To describe this region,

The marginal plains region is roughly equivalent to a very broad topographic arch that extends from the

suggesting a diachronous history of volcanic eruption and wrinkle ridge formation or reactivation

(older), the contact between unit fCm and corona flows from Seia Corona (unit fcSe) is vague.

an end member of a local phase of distributed volcanism, with smaller examples scattered nearby.

Unit fR surrounds the Muhongo Mons and associated small shield-sourced flow material (unit smM). In

relationships. Local contact relationships are detailed below.

spatial progression from Corpman to Romanskaya.

(described in the "Tectonic Structures" section).

unit mF with unit sfL is poorly defined.

mLh represents a late ponding even

include shield edifices and shield blotches (as defined above). Summit pits are rare. The contact between unit sRn

Unit fcZy correlates with unit cES in the V-37 quadrangle, which represents undivided flow material emanat-

A two-unit shield cluster (Ran Colles) lies within the western half of Rusalka Planitia, equivalent to the sin-

However, detailed contact relationships indicate that surrounding unit fR may locally lap onto Argimpasa Fluctus,

meters along the older channel bed. The southern expanses of unit sfL appear to have elevated dielectric constants Four large well-defined (and several subdued or small) coronae (defined as local elliptical or circular strucrelative to the rest of the region. Contacts and contact relations with unit fu and unit sfL are poorly defined locally. tural suites) occur with the V–25 quadrangle. Nearly without exception, V–25's coronae have raised topographic annuli surrounding a central basin hree major coronae dominate the Zaryanitsa Dorsa corona chain in V-25; from south to north, Hannahan-The oldest unit in the northern Rusalka Planitia region is the high-backscatter, deformed Poludnitsa Dorsa nas Corona, Bil Corona, and Heqet Corona adjacent to Iseghey Mons. Each is approximately 300 kilometers in basal material (unit bP; type locality at lat 10.5° N., long 179.5° E.), which emerges as thin ridge kipukas within diameter. The interiors of the coronae contain undeformed unit sfZy material. This relation could be explained by an elongate assemblage of moderate-backscatter, ~5-kilometer-diameter shields mapped as Poludnitsa Dorsa strain partitioning or it could indicate that the rate of local volcanic resurfacing has overwhelmed strain accumushield field material (unit sP; type locality at lat 3° N., long 179° E.). The shields are inferred to be volcanic edilation. A number of minor coronae and other volcanic features (defined by raised domes, and concentric fractures fices from their circular planforms despite the scarcity of obvious summit pits. Poludnitsa Dorsa flanks the eastand ridges), ranging from 10 to 100 kilometers in diameter, lie scattered between Bil Corona and Heqet Corona. East of Hannahannas Corona, a north-trending pit-chain swarm cuts through unit sfZy materials; the pit chains Low-backscatter, undifferentiated, canali-bearing flows (unit fu) lap onto Poludnitsa Dorsa. Locally, the surprobably represent dikes emanating from Saunau Corona in V–37. The Zaryanitsa Dorsa coronae chain has a strong effect on the regional structural fabric. Regularly spaced A small, 750-square-kilometer isolated kipuka of high-backscatter, blocky material (basal material near north-northwest-trending wrinkle ridges dissolve into a network of ridges that wrap around individual shields Lamashtu Mons [unit bLm], type locality at lat 3.3° N., long 173.8° E.) sits on a short ridge near Lamashtu Mons, (unit sZy) near the coronae annuli. At the annulus, the ridge network collapses into a closely spaced suite of surrounded by flow material of Rusalka Planitia (unit fR). This block of rugged material is cut by sharply defined ridges comprising the corona annulus. The individual annuli link up to form a broad anastomosing warp, Zaryanorth-northwest-trending grooves and north-northeast-striking scarps. The ribbon-and-ridge fabric of many tessera regions cannot be identified in unit bLm, which implies a different history than the ribbon-bearing tessera the regional wrinkle ridge trend, with maximum shortening perpendicular to Zaryanitsa Dorsa. Ituana Corona is an isolated 100- by 150-kilometer-diameter corona in Llorona Planitia. The corona is prined to the Rusalka Planitia region (flow material of Rusalka Planitia (unit fR), type marily defined by its topographic expression; many of the structures within the raised annulus appear to be locality at lat 5° N., long 173° E.), is separated from unit fu based on abrupt truncation of the fine-scale textures obscured by local shields. Faint radial and concentric lineaments, interpreted as dikes by their association with on unit fu and slightly higher backscatter than unit fu. The contacts between unit fu, unit mLm, and unit fR are shields, surround the corona. unconstrained in many places. On the basis of available contact information, the planitia topography apparently

Other coronae in V-25 are fragmentary. Jarina Corona forms a 250-kilometer-long elliptical basin having a controlled the emplacement of unit fR. The northern unit fR contact truncates the southern end of the canali Baltis

partial annulus surrounding part of the Asherat Colles shield field complex. Clonia Corona, a 100-kilometer-Vallis. The Vega 1 lander likely landed on either unit fR or unit fu material. Gamma ray spectroscopy indicated diameter ovoid corona deforms local basement materials (unit bCl) in central V-25. An arc of material embayed that the top meter of material at the landing site had the following composition: K, 0.45±0.2% mass; U, by undifferentiated flows within the unit sRk shield complex is interpreted as a breeched 90-kilometer-diameter 0.64±0.47 ppm; Th, 1.5±1.2 ppm (Lodders and Fegley, 1998). This composition is broadly compatible with tho-

at lat 6° N., long 163° E.), which apparently emanates from coronae associated with Zaryanitsa Dorsa, dominates V-25 includes several broad warps (dorsa), which are long-wavelength linear topographic highs thousands the Rusalka basin. The unit differs in radar properties on either side of Zaryanitsa Dorsa. To the west, high-backof kilometers long (fig. 4). Some are accompanied by kipukas of locally older material (for example, Poludnitsa scatter, rough (in GSDR data) unit fcZy material has digitate, feathered margins and some interior radar-dark

Dorsa); others appear to be independent of the mapped stratigraphy (for example, Yalyane Dorsa). An exception channels. The eastern portion appears to be topographically confined below a planetary radius of ~6051.5 kilo- is Zaryanitsa Dorsa, which represents an amalgamation of corona annuli. meters. Both areas are cut by wrinkle ridges and broad warps and are downwarped by 1000-kilometer-scale basin

Dorsa with distinct geologic units occur toward the edges of the planitia basins. Oya Dorsa (the southern extension of Vedma Dorsa in V-13) is the most prominent on the western slope of Llorona Planitia. A penetra-

The eastern part of unit fcZy (which includes Argimpasa Fluctus) has a lobate contact with unit fR. Western tive, north-northwest-trending ridge belt dominates the northern end of Oya Dorsa, but the short-wavelength unit fcZy has lower emissivity than eastern unit fcZy, which, combined with similar roughness and higher Fresnel folds fade to the south and are replaced by northeast-trending grabens. Both trends are associated with parallel reflectivity, suggests higher dielectric constants in (and thus compositional differences) western unit fcZy. A kilometer-scale reticulate ridge pattern of unknown origin deforms parts of western unit fcZy, whereas wrinkle ridges flows. The age relationship between the two near-orthogonal structural suites is unclear. Lumo Dorsa, on the northern edge of Llorona Planitia, is composed of kipukas of basal materials cut by sharp east-northeast-striking scarps, again superimposed on a broader, parallel warp. The interaction of Lumo Dorsa with successive submembers of unit fcIt suggests an extended history of warp growth. The regional wrinkle ridge orientation cuts across interactions with individual wrinkle ridges, illustrating the diachronous evolution of wrinkle ridges with respect both trends, but locally wrinkle ridges swing into parallelism with the warps. Rusalka Planitia is also bordered by dorsa: the north-south-trending Poludnitsa Dorsa lies to the east, and a short segment of ridge belt, bearing Clonia Corona, arcs around the northern boundary. Poludnitsa Dorsa's short

wavelength ridges appear to predate the emplacement of local volcanic shield material (unit sP); again, the regional wrinkle ridge trend is oblique to the broad warp orientation. Several warps without distinctive geology also occur in Rusalka Planitia, including Yalyane Dorsa in V-25 and Vetsorgo Dorsum in V-37. These relatively featureless warps, which regional wrinkle ridges parallel, bow up to a kilometer high with ~250-kilometer spacing. Although evidence in V-37 indicates warping began before the surface manifestation of the wrinkle ridges was imposed (DeShon and others, 2000), the initiation of the underlying wrinkle ridge suite is harder to date. Late shortening probably accommodated simultaneous long- and short-wavelength deformation, which would imply mechanical stratification of the lithosphere (Zuber and others, 1987). SMALL-SCALE POLYGONAL FABRICS

Kilometer-scale isotropic polygonal fabrics of high-backscatter lineaments have been interpreted as lavacooling joints or a response to abrupt local lithospheric heating by the mantle (Johnson and Sandwell, 1992) or abrupt cooling by the atmosphere (Anderson and Smrekar, 1999). Both of these models assume such fabrics are composed of lineaments with negative topography fractures. Two areas of these structures in V–25 challenge this assumption. At lat 1° N., long 173° E., unit sfZy embays polygonal-fabric-bearing unit fcZy. The lineaments comprising the fabric that cuts unit fcZy appear to track into the overlying flows, suggesting the lineaments represent positive (rather that negative) topography (fig. 5A). More compelling evidence lies in the low-backscatter ejecta deposit surrounding the crater Caccini near lat 17° N., long 170° E. At the edge of the halo, the polygonal fabric is indistinct; however, toward the crater the contrast between lineament and background increases (fig. 5B). This relationship suggests that a blanket of smooth or absorptive material lying between, rather than within, lineaments: thus the lineaments are positive rather than negative features, and represent ridges. Alternatively, the lin eaments may represent block-filled cracks far larger in scale than the layer of ejecta. Though this relationship does not imply all such fabrics are ridge networks, or that the strain imposed by isotropic tension (for example, lava flow cooling) did not play a critical role in the formation of such patterns, these relationships do indicate that these features should not be attributed to a singular thermal event. Again, the potential for reactivation also must be taken into account. The scale at which the original fabric formed (an important constraint for mechanical models) might not be the same scale that is currently visible.

Of V-25's nineteen impact craters, only three are larger than ~20 kilometers; 45-kilometer-wide Corpman in the southwest corner, 32-kilometer-wide Romanskaya in the northeast corner, and 38-kilometer-wide Caccini slightly northwest of the center of the map area (see table 1). West-facing extensional scarps deform both Corpman and Romanskaya. Flows from Caccini flow around wrinkle ridges, clearly indicating that this crater postdates a large component of local contraction. Extensive halos associated with craters, and the related issue of splotches, may be of more interest than the craters themselves (fig. 6). The craters du Chatelet and Caccini both have well developed ~500-kilometer-diame ter parabolic halos. Caccini's halo shows low-backscatter values and low emissivity; the du Chatelet halo has low-backscatter, low-emissivity arms surrounding a high-backscatter core. The majority of the other craters have irregular halos, generally accepted as representing the distal fine-grained component of impact ejecta; parabolas represent material entrained by the prevailing high-level easterly winds (Campbell and others, 1992). Ten crater less splotches (diffuse, dark centered, bright-bordered backscatter features) are probably shock features formed by the airbursts of meteors that fail to reach the surface (MacKinnon and others, 1997). Although craters are too scarce on Venus for useful dating of geologic units, the decay of crater halos might serve as an approximate index for the relative ages of individual craters (Izenberg and others, 1994). Conversely, dust from impacts and splotches both directly obscure geologic contacts (as in the example of Tie Fluctus mentioned above) and may contribute to the more homogeneous observed degradation in backscatter contrast between geologic units (Arvidson and others, 1992) that limits our understanding of material such as unit fu. A useful characteristic of these features is that they may highlight subtle structural features, including, in the case of V–25, the delicate northeast-trending lineament suite mentioned above.

The geology of the V-25 quadrangle records discrete histories of resurfacing in two topographic basins (Llorona and Rusalka Planitiae), superimposed on volcanic flows and basement kipukas that form a complex The earliest event recorded in the Llorona Planitia region is the emplacement of the basal materials. The basal units emplacement history is unconstrained. Presumably, these materials were volcanically emplaced; to imply another mechanism would require strong justification. Some of these materials clearly experienced north northwest-directed extension, as well as east-northeast-directed contraction at Oya Dorsa. The penetratively developed structures associated with both events may indicate a thin brittle layer in Llorona Planitia at that time Basal units are distributed in deformation belts (Oya Dorsa and Lumo Dorsa) and local topographic highs (Urutonga Colles) around the edge of the planitia basin, which may be a preservational artifact related to the regional Local volcanism continued after the above phases of small-scale, but regionally coherent, deformation that formed a patchwork of shield flows over Urutonga Colles and parts of Oya Dorsa. Northeast-striking fractures subsequently cut across these shields, especially to the south of Llorona Planitia. These fractures are part of a regional fabric of brittle deformation that extends over much of V-25 and V-37 to the south; this structural fabric likely reflects a single tectonic event, or it was driven by a small degree of concentric extension around the high lands of Aphrodite Terra. Individual stratigraphic relationships between fabric elements and geologic units, however, have been modified by tectonic reactivation. In parts of Llorona Planitia surrounding Urutonga Colles, the northeast-trending fabric, as well as the units it deformed, was buried by extensive undifferentiated flow material associated with canali. South of Yolanda crater however, an unnamed canali appears to weave around fractures that cut undifferentiated flows, indicating contrasting sequences of events from location to location. Locally superposed on the canali (which indicate extensive lava transport) is a mix of local patchy shields and extensive topographically confined flow fields that appear to issue from Ituana Corona. Crustal shortening produced east-trending wrinkle ridges in topographically lower portions of Llorona Planitia. The location of wrinkle ridges is controlled more by regional elevation than the host geologic unit; the implication is that the last increment of wrinkle ridge formation persisted past the majority of unit emplacement (although given the possibility of reactivation, the timing of when individual wrinkle ridges were initiated remains unknown). As outlined in Bilotti and Suppe (1999) and Sandwell and others (1997), the large-scale wrinkle ridge pattern likely reflects radial loading associated with the positive geoid anomaly of Aphrodite Terra, a key assumption being that the geoid in this area has not varied much since wrinkle ridge formation began. Contact relations indicate that longer wavelength deformation belt strain continued to accumulate throughout the stratigraphic sequence recorded in this basin The other basin in V–25, Rusalka Planitia, is also flanked by kipukas of basal units that presumably represent some of the oldest material in this region. In Poludnitsa Dorsa to the east of the Rusalka basin, east-west contraction preceded the local emplacement of low volcanic shields (unit sP), which in turn gave way to inundation by less viscous flows (the local origin of unit fu and unit fR). The Rusalka Planitia topographic basin appears to have evolved by the time later flows were emplaced; the distribution of unit fR appears to be topographically controlled. Subsequent extensive flows, apparently sourced from the chain of coronae that splits Rusalka Planitia in two, continued to fill the basin, interfingering with concurrent shield volcanism. Regional wrinkle ridges, presumably driven by loading associated with Aphrodite Terra, are partially inundated by unit fcZy flows; these tonic interpretation must account for such apparently diachronous regional winkle ridges give way to a presumably later wrinkle ridge complex controlled by local topography and

the earlier, underlying northeast-striking fracture suite. Corona evolution continued, with later flows likely being

contain internally consistent stratigraphy relations, the problems of contact obscuration by impact-related dust, as

illustrated by the interaction between Tie Fluctus and the halos of Yazruk and du Chatelet craters, undermines ou

confidence that unit fu represents a single rock layer. Almost by definition, undifferentiated flows cannot be used

as an independent stratigraphic constraint. On Venus, this problem limits our most precise geologic analysis to the

local and regional scale (for example, individual planitia) and severely hampers our ability to define uniquely

trapped within the emerging topographic annuli (strain partitioning is an alternative explanation). Zaltu Mons sourced flow material (unit mZa) bears mottled moderate-backscatter flows centered on a 600-The evolution of the Zaryanitsa Dorsa coronae proceeded in parallel with the construction of three large vol meter-high pitted dome, rimmed by circumferential fractures. The dome resides on a low east-west-trending warp canoes to the east, and the Ran Colles complex of shield edifices to the west. Flows that emerged from Ran suggesting a connection between the local volcanism and regional topographic development. One of the most Colles appear to have contributed to stratigraphically ambiguous undifferentiated flow materials to the west. striking features of Zaltu Mons is the suite of radial lineaments curving up to 250 kilometers out along a north-The overall historical theme for both Rusalka Planitia and Llorona Planitia is the continued evolution of a long-wavelength topographic basin in the presence of both extensive corona-related volcanism and regional shortening circumferential to central Aphrodite Terra. The data are also consistent with (but cannot uniquely Scattered kipukas of basal material and locally early edifice fields, some of which are associated with Clonia prove) progressive lithospheric thickening with time. Corona, lie within north-central V–25. These kipukas comprise basal material of Clonia Corona (unit bCl, type The regional history of the rest of V-25 is much harder to construct. Although there is ample evidence for locality at lat 15° N., long 166° E.) and shield field material of Clonia Corona (unit sCl, type locality at lat 16° distributed low-viscosity volcanism, local shield field and volcano development, all deformed by a semi-coheren pattern of wrinkle ridges and warps underpinned in places by northeast-trending lineaments, placing these elements in a unique temporal sequence has proved difficult. One attempt to resolve this problem in the V-25 region was conducted by Basilevsky and Head (1996). hese workers attempted to use three explicit stratigraphic markers (warps, followed by Baltis Vallis, and then by the regional wrinkle ridge network) and one implicit stratigraphic marker ("unit pwr1," in their map area approxi of gently rolling medium- to low-backscatter shields (unit sCl) are superposed on finely textured basal material of mately equivalent to unit fu in this map) to generate a directional geologic history for this region of Venus. At first glance, Baltis Vallis, a single simple channel ~6,800 kilometers long, would appear to represent an ideal stratigraphic marker. However, the report of Steward and Head (2000) hinted at a more complex, multiphase history with Baltis Vallis forming over the period of time during which warps and ridge belts also evolved. Even more significant problems come with the other two proposed stratigraphic markers. Basilevsky and Head (1996) attempted to use the distribution of warps to constrain the base of what is map ped here as unit fu. At least two classes of topographic warp appear in V-25; those bearing basal materials as A very high backscatter block of tessera (unit t) at lat 22° N., long 171° E. is deformed by orthogonal sets of ipukas (ridge belts) that cut across the regional wrinkle ridge trend, and those that simply bend earlier surround ing materials and tend to parallel the regional wrinkle ridge trend. It would be imprudent to use these two classes of ridges as a single temporal marker: indeed, there is no way to place unique temporal constraints or correlations (1998) explains this structural fabric as part of a progressive deformation in which the locally thin surface layer within these classes. Only the warps that parallel the wrinkle ridges deform Baltis Vallis. simultaneously cooled and deformed. Ribbon structures resulted from extension in one direction, and the spa-A more dangerous assumption concerns the wrinkle ridges themselves, which are portrayed by earlier worktially overlapping ridges resulted from shortening in the perpendicular direction. Ribbons likely formed first, ers as the result of a single deformation event. On the basis of that idea, the intersection of craters with individual ridges is used to obtain a relative age of the entire network. However, as shown above, the existence of a singular wrinkle ridge network in not supported by this study, which removes a primary requirement for such a dating The longest channel on Venus (and in the solar system) is Baltis Vallis, which lies east of unit t and unit sCl attempt (Campbell, 1999), even if the difficult task of deciding when crater breccias have been deformed by a wrinkle ridge had been successful. The implicit assumption that wrinkle ridges are monogenetic is also questiona-A vast complex of sequentially transgressive shield edifices mapped here as shield field material around ble and is an assumption inconsistent with the geologic relations described here. Romanskaya crater (unit sRk, type locality at lat 24° N., long 177° E.) extends well into the adjacent V–26 quad-The over-arcing question of the implicit stratigraphic marker (for example, unit pwr1) in studies such as rangle and dominates the map area near Romanskaya crater. The homogeneous moderate-backscatter shields typi-Basilevsky and Head (1996) requires confidence that a mapped remotely sensed unit actually correlates with a cally lack summit pits but have definite (although subdued) topographic relief. Little in the way of fine-scale single material unit that records a single geologic event. In V-25, although significant portions of the map area

robust (on the hemispheric to global scale) geologic relations or histories. REFERENCES CITED Anderson, F.S., and Smrekar, S.E., 1999, Tectonic effects of climate change on Venus: Journal of Geophysical Research, v. 104, p. 30,743–30,756. Arvidson, R.E., Greeley, Ronald, Malin, M.C., Saunders, R.S., Izenberg, Noam, Plaut, J.J., Stofan, E.R., and Shepard, M.K., 1992, Surface modification of Venus as inferred from Magellan observations of plains: Journal mechanics of wrinkle ridge formation is not well understood (Golombek, 1988; Watters, 1988; Schulz, 2000), of Geophysical Research, v. 97, p. 13,303–13,317. although workers agree that wrinkle ridges record a small degree of regional contraction. As such, recognizing Baker, V.R., Komatsu, Goro, Parker, T.J., Gulick, V.C., Kargel, J.S., and Lewis, J.S., 1992, Channels and valleys multiple phases of activation is difficult. However, for other structural suites, such as regular fracture patterns and on Venus-Preliminary analysis of Magellan data: Journal of Geophysical Research, v. 97, p. Banerdt, W.B., and Sammis, C.G., 1992, Small-scale fracture patterns on the volcanic plains of Venus: Journal of Geophysical Research, v. 97, p. 16,149–16,166. Banks, B.K., and Hansen, V.L., 2000, Relative timing of crustal plateau magmatism and tectonism at Tellus

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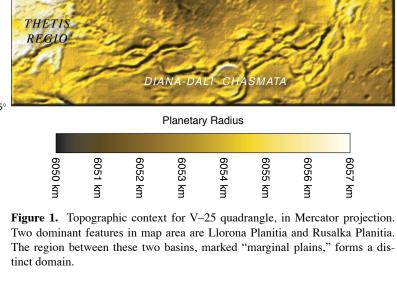
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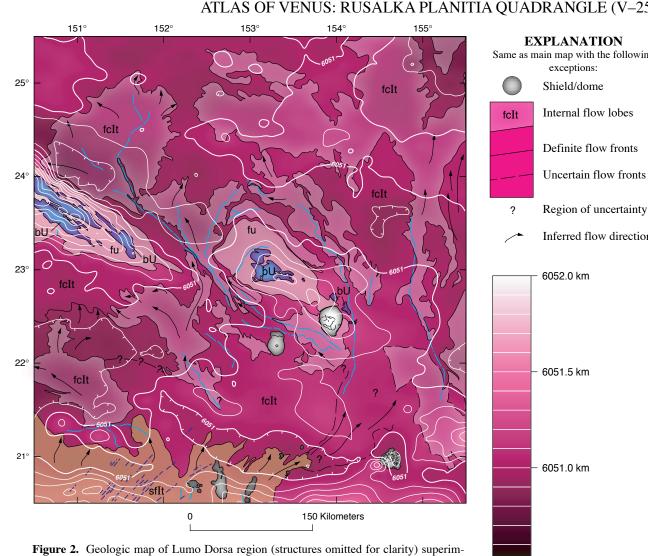
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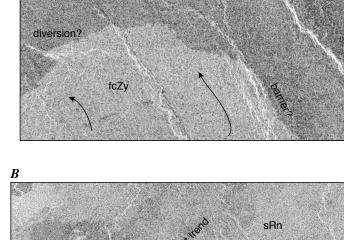
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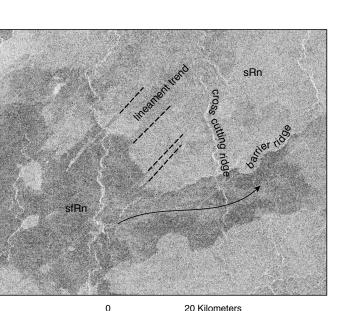
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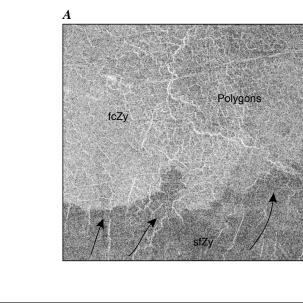
posed on gridded altimetry data having an effective horizontal resolution of 20 kilometers (Mercator projection). Topographic contour interval is 100 meters. Successive internal flow lobes of unit fcIt (flow material of Ituana Corona) appear to contour around kipukas comprising units fu and bU. Upper flow lobes, distributed by well-formed channel systems, pond in local depressions, which implies progressive topographic development of dorsa region during emplacement of volcanism associated with Ituana Corona. However, correlation of contacts and topography is not exact, which hints at either a more complex tectonic history or the correlation is at the resolution of altimetry and SAR data sets.





projection and east-looking in both cases. A, High-backscatter uni fcZy of Argimpasa Fluctus is interpreted as being diverted by topo wrinkle ridges have no apparent effect on this same flow unit. Arrows indicate interpreted flow direction. Image centered at 4.5° N., 175° E **B**, Ran Colles volcanic complex showing unit sfRn material flowed along an irregular bright lineament, which probably represents an early-formed wrinkle ridge (barrier ridge). A similar ridge structure boundary. This image also illustrates the interaction between north east-trending lineament suite, unit sfRn and unit sRn contact, and tractional reactivation of an earlier fracture suite. A reasonable tec

Figure 3. SAR images that illustrate interactions between wrinkle



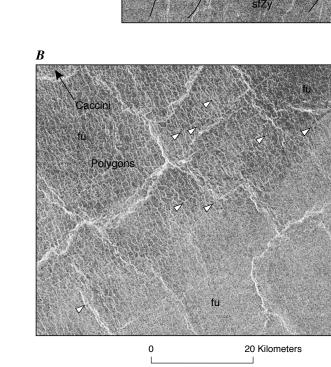
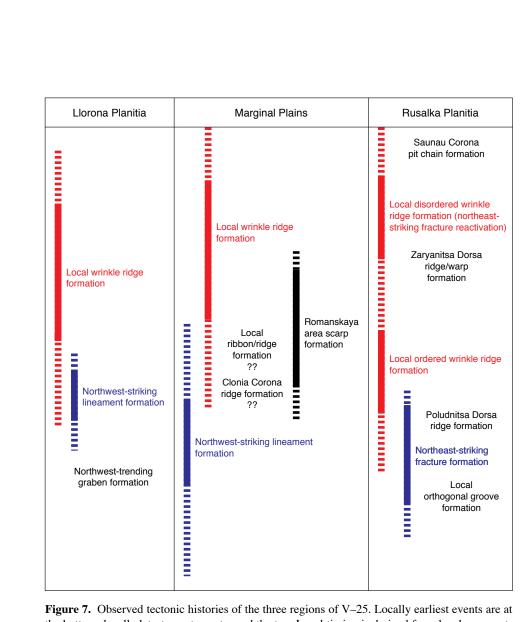
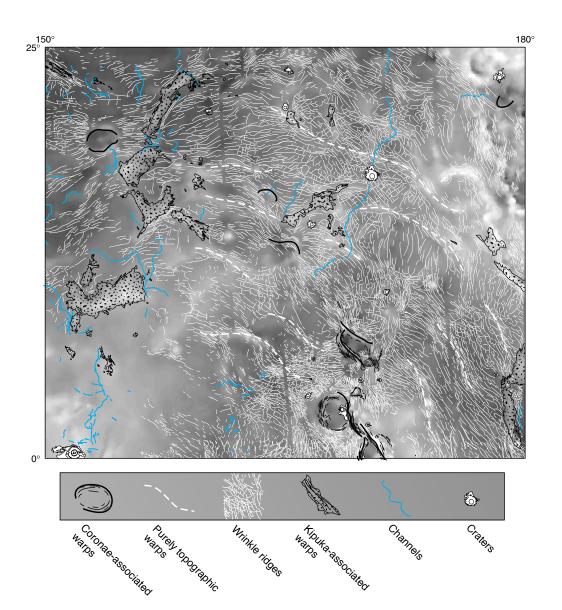


Figure 5. SAR images illustrating positive relief of some small-scale polygonal lineament patterns. SAR data are in sinusoidal projection and east-looking in both cases. A, Image centered at 1° N., 172.5° E. showing unit sfZy material that has flooded unit fcZy material tex tured with irregular ~4-kilometer-long lineaments. Arrows represent flow direction. Some lineaments penetrate overlying unit sfZy material and control parts of contact. Lineaments are interpreted as small ridges. **B**, Image centered at 17° N., 170.5° E. showing edge of parabolic halo that surrounds Caccini crater (trending NE across center of image). A clear polygonal texture, with a cell size of about one kilometer, is clearly visible within darker haloed region (polygonal texture should not be confused with the more prominent, 20-kilometerlong wrinkle ridge segments). This fabric is not immediately visible in lighter area but is hinted at in higher contrast views. If the dark halo is composed of fine impact ejecta, the fine ejecta would be expected to subdue fractures and enhance ridges. Also, note the faintly preserved fine east-northeast-trending lineaments (indicated by white pointers). These may be analogous in origin to the fine northeast-trending lineaments and fractures that occur at Ran Colles (see fig. 3B), Urutonga Colles, and near Fand Mons. Given the parallel orientation of one suite of wrinkles ridges in this image, the fine lineaments possibly represent fractures inverted as fine ridges (comparable with the ideas put forward in DeShon and others, 2000).



the bottom, locally latest events are toward the top. Local timing is derived from local cross-cutting relationships between structures and units. Robust correlations between the three regions cannot be constrained. The potential for structural reactivation and volcanic burial means preceding phases of tectonism may not have been identified. See text for details.



GEOLOGIC INVESTIGATIONS SERIES I–2783

Inferred flow direction

Figure 4. Mercator projection of a structural map of ridges and warps in V-25, illustrating three different classes of dorsa. The first (stippled), associated with kipukas of local basal material, represents deformation belts of other authors and are generally discordant with wrinkle ridge trends in V-25. The second (dashed white lines) represents long-wavelength topographic features that paral lel wrinkle ridge trend, implying either a common origin or a controlling structural inheritance from

one suite on another. The third class comprises those dorsa that surround coronae. Also, note corre-

lation between low elevations and wrinkle ridge density.

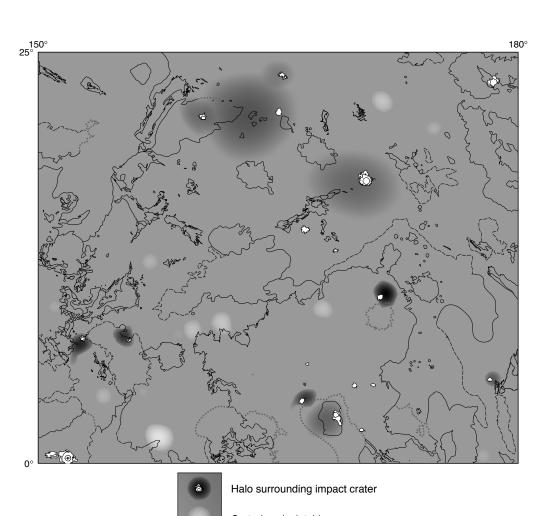
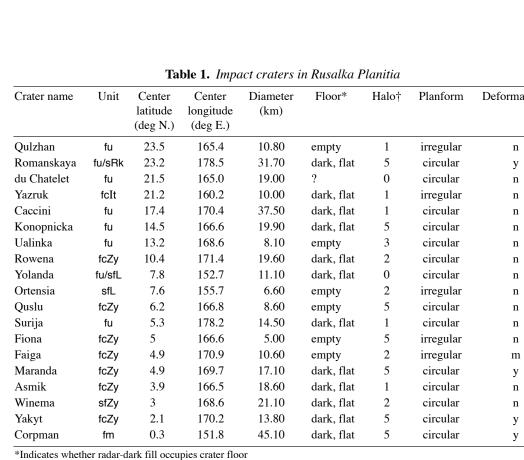
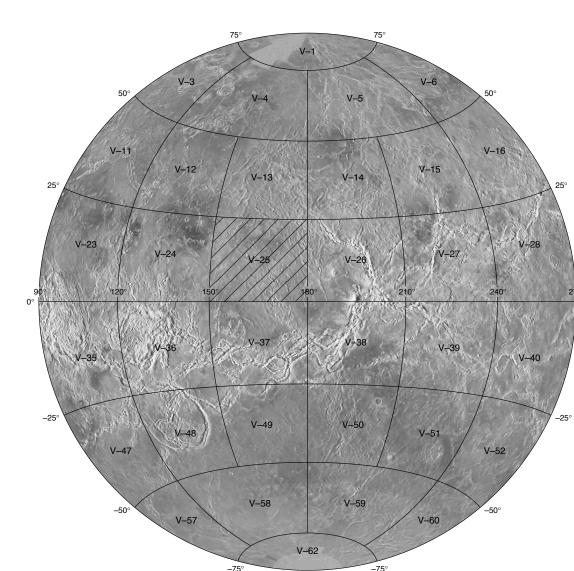


Figure 6. Mercator projection map of distribution of impact-related surficial deposits in V-25, compared to unit contacts. Crater halos obscure material unit contacts, especially in northern part of map area. However, halos and so-called craterless splotches (thought to represent meteor airbursts) enhance fine topographic lineaments (see fig. 5*B*)



†Range of values indicates well-preserved parabola with internal structure (0) to no dark halo (5), respectively, with ‡Ejecta, rim, or outflow cut by later tectonic structures (y); no part of crater deformed (n); ambiguous (m)



QUADRANGLE LOCATION Photomosaic showing location of map area. An outline of

1:5,000,000-scale quadrangles is provided for reference.

